Whether the carcinoma which follows in certain cases of Paget's disease is caused by these organisms, which presumably produce the cutaneous lesion, remains open for future investigation, as does also the question whether there are in cancerous tumours generally parasites of the same, or of an allied, nature, but which from their similarity to the cells of the infected tissues have hitherto escaped notice.

"On the Position of the Vocal Cords in Quiet Respiration in Man and on the Reflex-Tonus of their Abductor Muscles."

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Although the laryngeal phenomena attending the act of respiration in man have not escaped the attention of physiologists and laryngologists, yet investigation on this point has been comparatively limited and nothing like unanimity of views has been obtained. On the contrary, a perusal of the chapters devoted to the description of the mechanism of respiration in the admittedly best and most recent physiological text-books shows that there exists a very remarkable diversity of opinions, not merely on details or on points of secondary importance, but on the very question, whether the larynx plays an active *rôle* during quiet respiration in man or not.

Thus Hermann,* Dalton,† Landois, and Stirling‡ describe the glottis in man during quiet respiration as in a condition of rhythmical widening and narrowing; Grützner§ as forming a small triangle not differing considerably from that seen after death, the laryngeal muscles being in a state of inaction; Rosenthal‖ as being pretty widely open, this being due to some muscular action, not precisely described; Michael Foster¶ as sometimes in a state of rhythmical widening and narrowing and sometimes in the same state as seen after death, this being due to an equilibrium between the dilating

molluscum contagiosum is a disease due to the presence of Psorozoa; and both Darier and White, of Boston, have described similar Protozoa as being the essential cause of a rare form of skin disease, which has been named "keratosis follicularis" or "psorospermosis folliculaire végétante."

* 'Physiologie,' 1870, p. 156.

† 'A Treatise on Human Physiology,' 1867, p. 223.

‡ Hermann's 'Handbuch der Physiologie,' vol. 1, Part ii, p. 57, *et seq.*

§ 'A Text-book of Human Physiology,' 2nd edit., vol. 1, p. 252.

‖ Hermann's 'Handbuch der Physiologie, vol. 4, Part ii, pp. 231, 232.

¶ 'A Text-book of Physiology,' 1889, p. 548, and 1879 (3rd edit.), p. 604.

and constricting muscles; Vierordt* and MacKendrick† as being widely open; and Brücke‡ as being kept open during inspiration.

Three widely different conditions therefore are described as representing the actual laryngeal phenomena observed during quiet respiration in man, viz.:—

(*a*.) Rhythmical opening and narrowing of the glottis.

(*b*.) A condition of rest, the glottis being widely open.

(*c*.) A condition of rest, more or less corresponding to that seen after death.

The first of these descriptions, which dates back to prelaryngoscopic times, is probably the most universally accepted one. It is generally believed that even during quiet respiration, with each inspiration a very perceptible widening, with each expiration a correspondingly perceptible narrowing, of the glottis takes place.

The actual facts, however, little agree with this opinion. From the metric measurements of the glottis, to be described in full further on in this paper, it will be seen that only in a small percentage of cases (less than 20 per cent.) the vocal cords of healthy, quietly breathing adults make rhythmical excursions extending over 4 mm. or more, and that in over 80 per cent. the glottis either remains almost immovably open during both inspiration and expiration, or that the excursions of the vocal cords are hardly appreciable.

The truth of this statement can so easily be verified by laryngoscopic examination that it is not easy to understand how a different belief could so long have held its ground, though a good many explanations of this paradox may be advanced. Thus it may be that some physiologists have simply transferred observations made on animals (in which the rhythmic movements of the cords, as a rule, are much more energetic than in man) to human beings, or that they have drawn their conclusions from an insufficient number of observations on man, or that nervous persons, unaccustomed to laryngoscopic examination, were experimented upon, or that, by the application of the laryngoscope, reflex movements were produced, or finally, that the serious mistake was committed of ordering the persons upon whom the observations were made to "breathe quietly." Under any of the last-named conditions, but especially under the last one, the general type of respiration, in accordance with universally admitted experiences, is apt to change at once in the direction of either deepening or acceleration, and it is under these circumstances that appreciable rhythmic excursions of the vocal cords are seen.

But if a number of healthy, not nervous, adults, accustomed to the application of the laryngoscope, are examined by a skilful observer

* 'Grundriss der Physiologie des Menschen,' 1877, p. 528. See also p. 224.

† 'Text-book of Physiology,' 1889, vol. 2, p. 311.

‡ 'Vorlesungen über Physiologie,' 1881, p. 450.

without their attention being in the least drawn to their mode of respiration, it will be seen, as above stated, that only in a small fraction appreciable widening and narrowing of the glottis occurs, and that, in the overwhelming majority of cases, the latter, during both phases of respiration, forms an almost stationary isosceles triangle, such as described by Rosenthal. To obtain this result, however, all the conditions just mentioned must be rigidly adhered to.

Corroborative evidence concerning the almost quiescent state of the glottis in man during quiet respiration will be found in the text-books and writings of Czermak,* Luschka,† Riegel‡ Schech,§ Von Bruns,‖ Merkel,¶ Mandl,** Tobold,†† Stoerk,‡‡ Bresgen,§§ Gottstein,‖‖ Rosenbach,¶¶ Krause.***

Semeleder,††† Burow,‡‡‡ Prosser James,§§§ and Bosworth‖‖‖ merely mention the rhythmic excursions, and B. Fränkel,¶¶¶ though he does not directly speak of a state of quiescence, expressly states that even during expiration the glottis is wider open than when seen after death. The utterances of Sir Duncan Gibb,**** Türck,†††† Fauvel,‡‡‡‡ T. Solis Cohen,§§§§ and Sir Morell Mackenzie‖‖‖‖ allow of no definite conclusions as to these authors' views on the point at issue.

* 'Der Kehlkopfspiegel,' 1860, p. 36.

† 'Der Kehlkopf des Menschen,' 1871, p. 49.

‡ Volkmann's 'Sammlung klinischer Vorträge,' No. 95.

§ 'Experimentelle Untersuchungen über die Functionen der Nerven und Muskeln des Kehlkopfs,' 1873, p. 40.

‖ 'Laryngoscopie und laryngoscopische Chirurgie,' 1873, p. 101.

¶ 'Anatomie und Physiologie des Stimm- und Sprachorgans,' 1863, p. 120.

** 'Traité pratique des Maladies du Larynx,' 1872, p. 245.

†† 'Laryngoscopie und Kehlkopfkrankheiten,' 1874, p. 126.

‡‡ 'Klinik der Krankheiten des Kehlkopfs,' 1860, p. 68.

§§ 'Pathologie und Therapie der Nasen- Mundrachen- und Kehlkopfkrankheiten,' 1884, p. 34.

‖‖ 'Die Krankheiten des Kehlkopfs,' 1890, pp. 11, 12.

¶¶ "Zur Lehre von der doppelseitigen totalen Lähmung des Nervus laryngeus inferior (recurrens)" ('Breslauer aerztliche Zeitschrift,' Januar 24, 1890.—Reprint, p. 10).

*** "Experimentelle Untersuchungen und Studien über Contracturen der Stimmbandmuskeln" ('Virchow's Archiv,' vol. 98, 1884.—Reprint, p. 37).

††† 'Die Laryngoscopie,' 1863, p. 6.

‡‡‡ 'Laryngoskopischer Atlas,' 1877, p. 25.

§§§ 'Sore Throat,' 1878, p. 60.

‖‖‖ 'A Manual of Diseases of the Throat and Nose,' 1881, p. 16.

¶¶¶ In v. Ziemssen's 'Handbuch der spec. Pathol. u. Therap.' 2nd edit., vol. 4. —Reprint, p. 54.

**** 'Diseases of the Throat and Windpipe,' 1864, p. 453.

†††† 'Klinik der Krankheiten des Kehlkopfs,' 1866, p. 80.

‡‡‡‡ 'Traité pratique des Maladies du Larynx,' 1876, p. 79.

§§§§ 'Diseases of the Throat and Nasal Passages,' 1879, pp. 60 and 61.

‖‖‖‖ 'A Manual of Diseases of the Throat and Nose,' vol. 1, 1880, p. 242.

The nature of the question evidently renders it impossible to give absolute proof of the quiescence of the glottis in quiet respiration in man, but there cannot be the slightest doubt that repetition (under the necessary precautions) of the observations to be detailed hereafter will fully corroborate the statements concerning this point so far made, and for the purposes of the present investigation they may fairly be taken as proven.

If this then be granted, the question arises whether the quiescent state of the glottis as seen during tranquil respiration is identical with the condition seen after death (the cadaveric position) or whether during both phases of respiration the glottis during life is wider than it is in the dead body. This question is one of fundamental importance for the present investigation. If it were true, as assumed for instance by Grützner and Michael Foster, that the width of the glottis during tranquil breathing is identical with the cadaveric position, the larynx would be reduced, so far as its participation in normal respiration is concerned, to the passive *rôle* of an air-conducting tube, and would thus be put on a par with the trachea and the bronchi. This position of the vocal cords could be expressive of one of two conditions only, namely, either of a state of complete inaction of the vocal cords (Grützner), or what practically amounts to the same, of a state of complete equilibrium between the abducting and adducting forces (Foster). In either case there would be no active participation of the larynx in the function of respiration.

If, on the other hand, Rosenthal's, Vierordt's, and MacKendrick's contention were true, that the glottis is widely open during both phases of quiet respiration, or at any rate wider than after death, it would follow with logical necessity that the state of things seen during life represents neither an equilibrium between the antagonistic adducting and abducting forces, nor a state of inaction of both of them, but that it must necessarily be due to some actual muscular force which would be at work constantly during life. The result of the action of this force being that the glottis is more dilated even during quiet respiration than it is after death, this would obviously seem to signify that its function is to facilitate the act of respiration by allowing a freer ingress and egress of air to and from the lungs than would be possible if the vocal cords were either in a state of inaction or of balance of the antagonistic motor forces. The larynx then would not play a mere subordinate part in respiration as commonly supposed and come into action only as an accessory or associate in case of need, that is, during *forcible* respiration, but would be in a state of *permanent activity* during life, and those of its muscles which keep the glottis wider open during ordinary respiration than it is after death would, of necessity, belong to the class of *regular respiratory muscles* and would *deserve a more prominent position than has been hitherto accorded to them.*

An attempt will be made in this paper to show that the actual conditions correspond to the second of these two alternatives. The question has occupied my attention for a very considerable length of time, and as far back as 1884 I submitted the considerations of which this paper is an outcome to the opinion of the Laryngological Section of the International Medical Congress, at Copenhagen, in the discussion on "An etiological classification of the motor impairments of the larynx."*

On the same occasion Professor Krause, of Berlin, communicated his ideas on the reflex-tonus of the abductors of the vocal cords, ideas which fully harmonise with my own, and which shortly afterwards found full expression in his paper in Virchow's 'Archiv,' above referred to. They are exclusively based upon theoretical considerations.

In order to show that the glottis is wider open during quiet respiration (both inspiration and expiration) than after death, or after division of the vagi or recurrent laryngeal nerves, proofs of a threefold nature may be adduced, namely:—

First. Corroborating evidence from trustworthy observers.

Second. Direct comparative measurements of the width of the glottis during quiet respiration and after death.

Third. Results of experiments on animals.

a. Corroborating Literary Evidence.

In a previous paragraph, the names of those observers have been given who maintain that the glottis during quiet respiration is in a quiescent state. Of these observers, Rosenthal, Vierordt, Czermak, Luschka, Von Bruns, Schech, Riegel, Fränkel, Rosenbach, Krause, Gottstein expressly state that the glottis during both phases of quiet respiration is wider open than after death, whilst the opinion of almost all the other authorities named appears to go to the same effect, but is not so distinctly stated that they could be quoted as partisans of this view. On the other hand, one laryngologist only, namely, Mr. Lennox Browne,† expresses decided views as to the identity of the state of the glottis as seen during quiet respiration and after death.

He figures (Plate 10, fig. 92) the appearance of the normal larynx after death, showing the cadaveric position of the vocal cords, and adds (p. 334), "This is also their position during quiet respiration."

* A short reference to these observations will be found in the Transactions of the Congress ('Compte-rendu des travaux de la Section de Laryngologie,' Copenhagen, 1886.—Reprint, p. 48), but the work upon which they were based is now for the first time published.

† 'The Throat and its Diseases,' 1st edit., 1887.

The weight of evidence, therefore, is entirely on the side of the glottis being wider open during quiet respiration in life than after death.

b. Direct Measurements of the Width of the Glottis during Quiet Respiration in Man.

Surprisingly few direct measurements of the width of the glottis during quiet respiration have apparently been made.

In the childhood of laryngoscopy, graduated mirrors were recommended for making accurate observations concerning this and other points of physiological interest, and some short notice on such mirrors will be found in almost every text-book of laryngology.* On the whole, however, it appears that very little practical use has been made of these mirrors. Altogether, I find only the following metric† statements on the width of the glottis as seen during life and after death :—

Authors.	During Life.			After Death.	
	Position of rest during quiet respiration. Width of glottis.	Margins of respiratory excursions during ordinary respiration.	Width on deep inspiration.	Width of the glottis in	
				Men.	Women.
Luschka‡	8—10	..	..	5—6	3—4
V. Bruns§.....	8—10	..	..	..	..
B. Fränkel‖	..	..	..	5—6	3—4
Merkel¶	..	..	..	*ca.* 6	*ca.* 4
Huschke**	..	..	..	*ca.* 4	..
I. Solis Cohen†† ..	..	6—12	12—20	..	..
Morell Mackenzie‡‡	..	6—12	..	..	..

The numbers given in this table, however, for the following reasons, can only be used with great discretion. To begin with, Solis Cohen's and Mackenzie's statements have been added for the

* See, for instance, Merkel, *loc. cit.*, p. 5; Mandl, *loc. cit.*, p. 116; Semeleder, *loc. cit.*, p. 24; Türck, *loc. cit.*, p. 142; Mackenzie, *loc. cit.*, p. 224, &c.

† For convenience, I have reduced all of them to millimetres.

‡ *Loc. cit.*

§ *Loc. cit.*, and, p. 87, *ibid.*

‖ *Loc. cit.*

¶ *Loc. cit.*, p. 172 and 173.

** See Merkel, *loc. cit.*, p. 172.

†† *Loc. cit.*

‡‡ *Loc. cit.*

sake of completeness only, as it will be seen from the table that they give no direct measurements for quiet respiration, which in the present investigation alone is of importance. Moreover, the passages in their works in which the statements in question occur may be differently interpreted.* Secondly, only Luschka and Von Bruns give numbers *comparing* the different positions as seen during life and after death. Thirdly, it does not appear, from the statements of any of the authors quoted, whether their numbers are outcomes of direct *measurements* or of mere *estimates*, and even if the former, upon how many measurements their statements are based. Finally, and this is no doubt the most important objection against drawing definite conclusions from the above table, it is not stated in the writings of any of the authors quoted whether the numbers given by them, be they the outcomes of direct measurements or not, refer to the *actual* width of the glottis or to the *apparent* one, as seen in the graduated mirror.

I will, therefore, draw no inferences whatsoever from this table, and only direct attention to the facts that, with all these shortcomings, (1) the minimum of the numbers given for the position of rest by Luschka and Von Bruns is larger than the maximum of the width after death, as given by all the observers who have expressed this in numbers (Luschka, Von Bruns, Fränkel, Merkel, and Huschke); and that (2), even if we were to take into consideration the rhythmical excursions as given by Solis Cohen and Mackenzie, their minima would just correspond to the stated maxima of the width of the glottis in the dead body.

As I felt, however, that the evidence on this point, for the reasons above given, was by no means conclusive, I began this investigation by making a large number of direct measurements of the width of the glottis in adults during quiet respiration and after death. The number of my observations on living persons amounts to fifty, that on dead bodies to twenty-five.† I need not say that in every instance the measurements were made with great care, strictly in accordance with the rules enumerated in a foregoing paragraph, and that in every case of observation of the living subject the graduated mirror was repeatedly introduced, and the average taken from the numbers gained. It may, however, here be stated that in one and the same person, unless his attention be called to his mode of breathing or

* Solis Cohen says, "The space across will vary ordinarily from three to six lines, but when widely dilated by a deep inspiration it may be from six to ten lines, leaving a space large enough often to admit a good sized finger." Mackenzie says, "On inspiration they (the vocal cords) appear almost to touch each other at their anterior insertion, but to be separated from ¼ to ½ an inch posteriorly."

† For some time I examined the larynges of all adults of whom a *post-mortem* examination was made in St. Thomas's Hospital.

extraneous causes influence his respiration, the state of the glottis during tranquil breathing remains pretty constant, as I have ascertained by measuring several persons on different days, and by comparing the results thus obtained.

As to the method, I availed myself of a mirror on which a millimetre scale is engraved in such a direction that when the mirror is held in the correct position the scale stands parallel with the plane to be examined, that is to say, the distance between the inner borders of the arytenoid cartilages. The source of confusion which this arrangement undoubtedly entails, viz., that the marks of division of the scale are themselves reflected in the mirror if the latter be held in the correct position, that is to say, at an angle of 45° towards the horizon, is easily eliminated by a little practice.

There is, however, another point of the greatest importance with regard to the exactitude of the measurements, and one which, with the exception of a passing remark of Mandl's (*loc. cit.*, p. 116), I find to my surprise is not mentioned by any previous observers who speak about the use of these graduated mirrors; I refer to the considerable difference of the *actual* from the *apparent* length of the distance measured. The distance between the inner surfaces of the arytenoid cartilages, as apparent on the scale engraved on the laryngeal mirror, is not equal to the real distance, but considerably smaller than this, and the proportion between the real and the apparent lengths is, according to the principles of physiological optics, the same as the proportion between the real distance of the object, on the one hand, and the distance of the mirror, on the other, from the observer's eye respectively.

The real distance of the object (*i.e.*, the level of the glottis) from the observer's eye is of course equal to the distance of the observer's eye to the centre of the mirror plus the distance of the centre of the mirror to the object.

If we therefore assume, with B. Fränkel (*loc. cit.*, p. 16), that the average distance of the observer's eye from the centre of the mirror is 22 cm. (of which 14 cm. go to the distance to the mouth of the person examined, and 8 cm. to the distance from the mouth to the mirror), and that in an adult man of middle size the average distance from the centre of the mirror to the glottis is 8 cm. (in an adult woman 6 cm.) we obtain, if we call the apparent lengths of the base of the glottic triangle as seen during quiet respiration in the mirror a, and the real length which is wanted x, the following proportions*:—

* The same result is obtained if the ratio of the size of the scale on the mirror to the real size of the object be enquired into. If the distance from the eye to the mirror = A, and the distance from the mirror to the object = B, the whole distance from eye to object = A + B; the apparent size of the object will be to that of the scale on the mirror as $\frac{A}{A+B}$.

In man : 22 : 30 = a : x.
In woman : 22 : 28 = a : x.

Whence it follows that in men : x is equal to $\frac{30a}{22}$ or = a 1·36. In women: $x = \frac{28a}{22} = a$ 1·27.

It is obvious that in spite of all these precautions no absolutely correct numbers can be obtained, because, on the one hand, the distance of the observer's eye, even if he be emmetropic, is not always exactly equal to 22 cm. from the centre of the mirror, and, on the other, the distances of the level of the glottis from the centre of the mirror as given above for men and women are only *average* figures, from which the exact figures in individual cases might not inconsiderably differ. Still I have found by measuring in a double manner a large number of dead larynges in order to control my laryngoscopic measurements (viz., by first examining them with the graduated mirror, whilst the conditions of life were as carefully as possible imitated so far as position, distances, &c., are concerned, and by afterwards introducing a fine compass into the larynx, and measuring directly the distances between the inner surfaces of the arytenoid cartilages), that with sufficient practice nearly accurate results are obtained by direct measurements. The maximum error committed in measuring laryngoscopically was 1 mm., the average $\frac{1}{2}$ mm., while in a large number of cases the laryngoscopic and direct measurements completely corresponded with one another.

Of the measurements of dead larynges, it has already been stated

Thus if A = 22
and B = 8
A + B = 30 = the distance (if the person examined be an adult man).

The ratio of size of scale to the object will then be = $\frac{22}{30} = 0{\cdot}733$; *i.e.*, 0·733 mm. on the mirror scale correspond to 1 mm. real size.

If the eye be removed to a small extent further from the mirror, say to 24 cm. instead of 22 cm., the result will not be very different, as both the numerator and denominator will be increased. In the first case, as before stated,

$$\frac{22}{30} = 0{\cdot}733.$$

In the latter

$$\frac{24}{32} = 0{\cdot}75.$$

The real size (x) will then be to the apparent (a) = 1 : 0·733, or $x = \frac{a}{0{\cdot}733}$.

This gives the real width of the glottis in adult men.

In women $x = \frac{a}{0{\cdot}75}$.

I am much obliged to Mr. Stevenson for having given me this formula.

that a large number of them were examined by both laryngoscopic and direct methods; the remainder were measured directly. It need hardly be added that all undue traction, pressure, or, in short, anything that could possibly tend to disturb the natural condition of the parts was carefully avoided. To obviate the objection that the natural condition might have been disturbed by the mere removal of the larynx from the body, prior to the distance in question having been ascertained, I have made some laryngoscopic measurements on dead bodies before the *post-mortem* was commenced,* and have compared the results thus obtained with the laryngoscopic and direct measurements taken afterwards when the larynx had been removed from the body. It was found that the width of the glottis had not been altered by the removal of the larynx.

I now proceed to quote the results I obtained.

In a total number of 50 persons whom I have methodically examined with the graduated mirror during quiet respiration, I have only found regular and considerable rhythmical movements eight times. Considerable movements I call all such, in which the excursions of the cords influence the width of the glottis during the two phases of respiration to an extent of more than 4 mm. Of the remaining 42 persons examined, 23 were men, 19 women. In all these cases during quiet respiration the glottis remained either immovably open, or the excursions of the cords were so slight as to easily allow of estimating the average width of the glottis. Subjoined are the results of my experiments, expressed in millimetres, both the apparent and the real size being given in round numbers.

* I may state here, that, according to repeated examinations of my own, rigor mortis in man exercises no influence upon the width of the cadaveric glottis.

Males.			Females.		
Age.	Average size of the glottis.		Age.	Average size of the glottis.	
	Apparent.	Real.		Apparent.	Real.
32	8	11	19	8	10
36	9	12	26	8	10
28	9	12	34	10	12·5
22	10	13·5	33	8	10
34	9	12	28	9	11·5
55	7	9·5	60	7	9
46	9	12	43	8	10
53	10	13·5	25	10	12·5
48	10	13·5	44	9	11·5
26	12	16	53	8	10
27	10	13·5	19	8	10
30	9	12	22	7	9
44	8	11	22	10	12·5
28	10	13·5	34	11	14
20	7	9·5	21	10	12·5
53	11	15	45	9	11·5
59	10	13·5	37	12	15
45	9	12	26	10	12·5
19	10	13·5	21	9	11·5
23	14	19			
58	9	12			
22	8	11			
60	11	16			

From these tables it will appear that my own measurements on the whole agree, so far as the apparent distance is concerned, with those of Luschka and Von Bruns, who alone have expressed these conditions in numbers. I can only assume that both these authors speak of the apparent, not of the real, size when stating that the average width of the glottis in both cases varies from 8 to 10 mm.; this, it is seen, is also the average of the apparent size in my own measurements, the maximum being in men 14,* in women 12 mm., and the minimum in both cases being 7 mm. The exact average as resulting from my observations would be in men an apparent width of nearly 10 mm., corresponding to an actual width of 13·5 mm., and in women an apparent width of exactly 9 mm., corresponding to an actual width of 11·5 mm. I cannot say that I have been able to make out any distinct relationship between the widths of the glottis and the ages or statures of the persons examined.

* This figure, corresponding to 19 mm. real size, entirely confirms the apparently somewhat exaggerated descriptions given by Czermak and Solis Cohen, who state that the glottis in some cases, even during quiet respiration, would admit a good sized finger.

The following are my results as to the width of the cadaveric glottis:—

Men.		Women.	
Age.	Real size of cadaveric glottis.	Age.	Real size of cadaveric glottis.
35	5·5	21	6
17	4	40	2
24	5	27	4
23	5	56	2·5
43	4·5	54	4·5
50	5	58	3·5
54	6	33	4
63	4	23	4·5
53	3·5	60	5
26	4		
45	5		
27	3·5		
60	5·5		
77	4·5		
35	5		
48	5		

Here again on the whole, my results agree with those found by previous observers (Luschka, Von Bruns, B. Fränkel, Merkel, Huschke). In 16 larynges of adult males I found a maximum width of 6, a minimum of 3·5 mm., whilst the average was very nearly 5 mm.; in 9 larynges of adult females the maximum width was 6, the minimum 2 mm., the average exactly 4 mm.

It can be positively stated that no relationship exists between the cadaveric widths of the glottis and the ages or statures of the bodies, since the maximum width seen in the female (6 mm.) was observed in a small woman, who had suffered from tuberculosis of the lungs; the minimum width seen in a man (3·5 mm.) was observed in a tall lad of 19 who died from renal disease.

At the same time I must not omit to observe that the remarkable differences in the width of the cadaveric glottis as shown by the last table, especially in females (from 2 to 6 mm.) make it to my mind rather doubtful whether the expression "cadaveric position of the vocal cords" is a very significant and useful one.

In an isosceles triangle of 20 mm. length, this being the average length of the glottis in females, it makes a very considerable difference in the position of the sides whether the glottis be 2 mm. or 6 mm. in length.*

* The last-named fact appears to be of considerable importance, with regard to

If we now compare the summary of the two last tables showing the width of the glottis during quiet respiration and after death respectively, the results will be found to be rather surprising.

The width of the glottis in adults expressed in millimetres is:—

In men.	Average.	Maximum.	Minimum.
During quiet respiration { apparent size	10	14	7
{ real size	13·5	19	9·5
After death	5	6	3·5

In women.	Average.	Maximum.	Minimum.
During quiet respiration { apparent size	9	12	7
{ real size	11·5	15	9
After death	4	6	2

In other words, first, *during quiet respiration the width of the glottis in both sexes* is on the average not only fully twice the size or more of the glottis as seen after death, as would appear from mere laryngoscopic estimation, but *in reality twice and a half to nearly three times that size.*

Secondly, if, instead of the averages, the maxima and minima respectively be compared, the differences in some instances are even larger.

Thirdly, under all circumstances the minima as observed during life are greater than the maxima seen after death.

Thus all metric observations go to prove beyond any doubt that the glottis during quiet respiration is much wider open than after death.

Thirdly.—Experiments on Animals.

Concerning the last category of proofs, to the effect that the glottis is wider open during quiet respiration than after death, namely, experiments on animals, I am able to state that from the first experimenter—Legallois, down to the present day, all physiologists who have performed division of either both pneumogastric or both recurrent nerves on animals, and whose works on the subject have been

the different descriptions by authors, as to what may be called paralysis of the recurrent laryngeal nerve and what abductor paralysis.

accessible to me in the original, namely, Legallois,* Reid,† Longet,‡ Traube,§ Rosenthal,‖ Dalton,¶ Georg Schmidt,** Schech,†† Steiner,‡‡ Vierordt, jun.,§§ unanimously state that after such division the glottis became narrower than it had been previously; and this in fact is a statement which will be found in every text-book of physiology.

This category of proofs, however, obviously again can only be used with great restrictions for the decision of the point at issue. In the first place, of the authors just named, only Legallois, Reid, Traube, Schmidt, and Schech state distinctly and unmistakably that the narrowing of the glottis of which they speak as a sequel to the division of the pneumogastric and recurrent laryngeal nerves refers to the difference of the position of the vocal cords thus obtained from the one previously seen during *quiet* respiration. It can hardly be doubted that, also, the other authors quoted above think of this difference when they speak of the narrowing resulting from the division; but, unfortunately, their statements on this important point are not so unequivocal as to altogether exclude the objection that they had intended to contrast the position resulting from the division of the motor laryngeal nerves with that observed during *deep inspiration*.

Secondly, the conditions of quiet respiration in men and animals, so far as my own observations during a long-continued series of experiments on the functions of the motor laryngeal nerves and on the central innervation of the larynx undertaken in conjunction with Professor Victor Horsley permit me to conclude, are so different from each other, in that the quiet respiration of animals is much more usually accompanied by rhythmical excursions of the vocal cords than in men, that too much stress must not be laid on experiments in animals with regard to this point.

Thirdly, there exist undoubtedly frequent and important anatomical

* 'Expériences sur la principe de la Vie,' 1812, p. 197; and 'Œuvres,' 1830, vol. 1, pp. 170, *et seq.* and p. 248.

† 'Physiol., Anatom. and Pathol. Researches,' 1848, p. 118. His paper on this subject was published in 1841.

‡ 'Gazette Médicale de Paris,' 1841, p. 469, and 'Traité de Physiologie,' vol. 3, p. 529.

§ 'Beiträge zur experimentellen Pathologie und Physiologie,' 1846, fasc. 1, p. 95, *et seq.*

‖ 'Die Athembewegungen u. ihre Beziehungen zum Nervus Vagus,' 1862, 77.

¶ 'A Treatise on Human Physiology,' 1867, p. 451.

** 'Die Laryngoscopie an Thieren,' 1873, p. 31, *et seq.*

†† 'Experimentelle Untersuchungen über die Functionen der Nerven u. Muskeln des Kehlkopfs,' 1873, p 31.

‡‡ 'Die Laryngoscopie der Thiere.' Reprint from 'Verhandlungen des Natur. hist. Med. Vereins zu Heidelberg,' N.S., vol. 11, Heft 4, p. 287.

§§ 'Beiträge zur experiment. Laryngoscopie.' Diss. inaug., 1876, p. 39.

variations of nerve supply, not only in different kinds of animals, but even in animals belonging to the same species; and again, as will hereafter be shown, the immediate effects of the division of the motor nerves of the larynx, as well as its ultimate consequences, are different according to the age of the animals used for the experiments.

Thus, unless care is taken, all these circumstances combine to reduce, in this particular question, the value of experiments on animals for the solution of the corresponding question in men. Still, even if regard be had to all these circumstances and possible sources of error, the fact remains that by *all* observers narrowing of the glottis in all kinds of animals has been reported after division of the motor nerves of the larynx, and that by some of these observers the state of things thus resulting is expressly contrasted with the position as previously present during quiet respiration.

A general survey of the mass of evidence so far accumulated proves beyond doubt that the glottis is wider open during quiet respiration (inspiration and expiration) than it is after death or after division of the pneumogastric and recurrent laryngeal nerves. The statements of the most trustworthy and experienced observers on men, the reports of all physiologists who have investigated this question by experiments on animals, and especially the direct comparative measurements of the glottides of quiet-breathing healthy adults and of dead adult bodies—all go to establish one and the same result, and leave, I think, no doubt as to the actuality of the fact that the glottis in man during quiet respiration is wider open than after death.

The immediate outcome of this result is, as already stated in a previous paragraph, that the position of the vocal cords during quiet respiration can neither represent an equilibrium between the antagonistic adductor and abductor muscles of the larynx, nor the result of inaction of both of them. In either of these two hypothetical conditions the width of the glottis during quiet respiration could not but be identical with that seen after death.

As matters actually stand, the state of the glottis during quiet respiration must necessarily be the result of *active muscular contraction*, and must represent one of two conditions, viz., either simultaneous activity of both the adductors and the abductors of the vocal cords with preponderance of the latter, or, secondly, some degree of activity on the part of the latter alone—the adductors being not at all in a state of functional activity. An attempt will be made hereafter to show that the second of these alternatives in all probability corresponds with the actual facts. But before proceeding to a discussion of this point, the question which naturally arises from the fact that the glottis is wider during quiet respiration than after death demands a reply: What is the *cause* of this difference?

A reply to this question will be given by a consideration of the physiological functions of the larynx.

The larynx serves two functions, which are in a certain sense intimately connected with, yet in another sense just as distinctly antagonistic to, each other. These are the functions of respiration and of phonation. For the purpose of the former—which with regard to the vital interests of the individual is by far the more important one of the two—it is indispensable that the lumen of the air tubes should be wide enough open to admit of the ingress and egress of the quantity of air necessary for breathing purposes, without at the same time imposing an additional labour upon the other respiratory muscles. Such an additional labour would arise if the portal for the entry and exit of air were so narrow that the air, instead of quietly passing, had, by forcible means, to be sucked through it.

On the other hand, the function of phonation makes it a necessity that an apparatus should be interpolated within the air tubes which would admit of complete juxtaposition of the voice-producing organs.

This interpolation, in all probability, was meant for the purposes of phonation only, not primarily for respiratory purposes.

I am perfectly well aware that in a certain sense the interpolation of the phonatory apparatus, represented by the vocal cords, subserves also the protection of the lower respiratory passages against the entry of foreign bodies: but that this interpolation is not indispensable is conclusively shown by comparative anatomy. The purpose of protection is, indeed, as demonstrated by the latter science, sufficiently provided for by the "constrictor vestibuli laryngis" (Luschka) or "thyreo-ary-epiglotticus" muscle (Henle), which forms the uppermost stratum of the sphincter muscles of the larynx. In Reptiles a sphincter of the simplest form surrounding the vestibule of the larynx is the only protective arrangement (Henle, 'Anatomie,' vol. 2, p. 249), and even in dumb *Mammalia* the same simple arrangement returns. "In the Cetaceous Mammalia," says Mayo ('Outlines of Human Physiology,' 1839, p. 380), "which are dumb, we find a respiratory larynx alone; the windpipe terminates in a contractile circular aperture, and this opens not at the root of the tongue, but is prolonged as a pipe towards the nostrils completely out of the way of food." In man, again, a contraction of the constrictor vestibuli of the larynx sufficiently guards the lower air passages against the entry of foreign bodies, as shown by the numerous cases in which, though destruction of the phonatory apparatus (vocal cords) had taken place through disease, yet accidents from food, &c., "going the wrong way" occur no more frequently, than in people in whom these parts are intact.

Thus comparative anatomy as well as pathological observation on men combine to show that the interpolation of the vocal cords is by

no means an indispensable adjunct to the purposes of the respiratory process.*

On the other hand, in order to impart vibrations to the column of air contained in the upper respiratory passages for the purpose of producing sound, nature chose as the most suitable form a reduplication of folds of mucous membrane within the larynx endowed with certain special characteristics.

But this reduplication in turn seriously interferes with the calibre of the tube; that is to say, with the respiratory function of the larynx.

That this interference is serious can easily be shown anatomically, and, though not quite so obviously, with the material at present in our possession, both physiological and pathological.

For the first purpose I have made the following measurements† of dead larynges:—

Age of subject.	Transverse diameter of vestibule of larynx.	Width of glottic base.	Total length of glottis.	Longitudinal diameter of cricoid cartilage immediately beneath vocal cords.	Transverse diameter of cricoid cartilage immediately beneath vocal cords.
(*a.*) Males—					
23	18	5	25	15	16
50	16	5	24	16	16
43	17	4·5	24	16·5	17
54	17	6	22	18	19
63	17·5	4	23	18·5	18·5
(*b.*) Females—					
33	13	4	20	13	13
23	13	4·5	20	13	14
60	14	5	21	13·5	14

From this table it appears that the transverse diameter of the vestibule of the larynx, on the one hand, and the longitudinal and the transverse diameters of the cricoid cartilage, on the other, are so nearly equal to each other, that in both sexes, without committing

* At the same time it is perfectly possible that in *some* species of animals the complete closure of the glottis is by far the most important means of protecting the lower air passages against the entry of food. With regard to this very complicated question, see the excellent prize essay of Otto Frey, 'Die pathologischen Lungenveränderungen nach Lähmung der Nervi Vagi,' 1877, p. 81.

† My numbers referring to the total length of the glottis in men differ somewhat from those of previous observers in that they are a little smaller; the accuracy of the observations, however, can be vouched for.

any considerable error, the space above and below the vocal cords and ventricular bands might be looked upon as a circle. Selecting now the average radius resulting from the comparison of my measurements as the representative of the circle, we find in the five measurements of male larynges that its average would be about 8 mm. The area, therefore, in adult men of the air-tube above and below the phonatory apparatus would be about 200 square mm. In women the average radius would be 6·5 mm.; the area of the air-tube above and below the phonatory apparatus would be therefore about 133 mm.

Now, the average length of the glottic triangle in men after death is a little more than 23 mm., its base, as shown before, is 5 mm.; the area of the space included by the sides of the glottic triangle in men after death, therefore, is about 57 mm.

In women, the average length of the glottis would be 20 mm., its width, as shown before, is 4 mm.; the area of the glottic space, therefore, 40 mm. This means, in other words, that in adult individuals of both sexes the space for the entry of air is reduced by the interpolation of the phonatory apparatus when its constituent parts are at perfect rest to *less than one-third of its natural area.*

Anatomically, therefore, there can be no question as to the gravity of the diminution of the air channel, and the more so because it must not be forgotten that, even apart from the interpolation of the phonatory apparatus, the larynx and trachea represent the narrowest part of the whole air passages, both the uppermost part of the air passages and the aggregated diameter of the bronchi being considerably larger than the calibre of the first-named parts.

Physiologically, the question immediately arises: Is so considerable a diminution of the lumen of the air passages as that produced by the interpolation of the phonatory apparatus when at complete rest compatible with what we call at present the normal type of quiet respiration?

In this sentence the expression "normal type of quiet respiration" demands further explanation. It is by no means the purpose of this paper to show that, even if the glottis during life was identical with that seen after death, necessarily that state of laboured respiration which we call "dyspnœa" would arise. Obviously, if the interference caused by the diminution of the calibre be not excessive, a condition of things could be imagined in which this diminution was counterbalanced merely by what is called "hyperpnœa," *i.e.*, either an increased labour of the muscles normally engaged in quiet respiration (diaphragm, intercostal muscles, and scaleni), or additional efforts of the so-called "accessory" muscles of respiration. Under such circumstances, though one could hardly speak of the presence of actual dyspnœa, yet, undoubtedly, the state of things thus created would be different from what is at present the general idea of quiet

respiration in man. It will at once be seen that it is necessary to define this point very clearly, because, as already mentioned before, this part of the investigation is beset with very considerable difficulties.

Whilst, up to this point, the main part of our argument has been based on physiological observations on the human subject, and clinical facts and experiments on animals were only used as corroborative evidence, in this part of our enquiry we have to depend exclusively upon the two last-named factors, and for various reasons neither of them gives us so distinct a reply to the question at issue as would be desirable.

First, with regard to experiments on animals.

It has already been stated in a previous chapter that the conditions resulting from section of the laryngeal motor nerves in animals vary very considerably according to species, age, and individual peculiarities of the animals experimented upon, and that, practically, the only point on which a complete consensus of opinion has been obtained consists in the fact that narrowing of the glottis has been described by all observers. To what degree, however, this narrowing interferes with the respiratory functions of the animal operated upon is a question the replies to which vary very considerably.

The importance of the difference of species and of ages of the animals experimented upon for the decision of this point did not escape the acute observer who first thoroughly studied the influence of the division of the recurrent laryngeal nerves upon life, viz., Legallois. Having observed that in very young dogs the division of these two nerves led to speedy death by asphyxia, he wished to know whether the same phenomena were present in other specimens of animals. He therefore cut, he tells us,* sometimes the pneumogastric, sometimes the recurrent laryngeal, nerves in cats, rabbits, and guinea-pigs, in the first days of their existence. He found that "cats died in the same manner, and perhaps even more quickly than dogs; that in guinea-pigs and in rabbits, section of the recurrents obstructs the glottis less completely, the former only die in about an hour's time, and the rabbits after a half hour."

Having thus stated the differences in degree depending upon the *species* of the animals, Legallois proceeded towards determining the influence of *age* upon the phenomena resulting from sudden diminution of the calibre of the glottis. He found that "section of the recurrent nerves produces a less considerable suffocation in inverse proportion to the age of the animals; thus, in dogs and cats about two to three weeks old, this operation still causes dyspnœa, which, though less strong than in the first days after birth, yet is strong enough to cause the death of the animals after a few hours. At the

* 'Expériences sur le Principe de la Vie,' 1812, pp. 190, *et seq.*

age of three months or more, dogs are no longer so inconvenienced as to die; cats are much more so, and as soon as one excites them and forces them to walk they fall down as though they were suffocated."

Similar conditions obtain in rabbits and guinea-pigs. "The dyspnœa which is caused in their case by division of the recurrent nerves is less grave in proportion to their ages, but it is always more severe in guinea-pigs than in rabbits. For instance, the latter are much less inconvenienced by it at the age of one month than guinea-pigs at the age of five months, which may still perish from it within twenty-four hours."

"The reason of all these differences," continues Legallois, "is easily understood. It consists in the fact that, in proportion to the capacity of the larynx, the opening of the glottis in animals of the same age is greater in one species than in another, and still greater in the adult than at the moment of birth in those of the same species, as already stated by M. Richerand in the human species.* Or assuming that the form of the glottis, on the whole, is similar in these diverse animals, inasmuch as the areas of the smaller figures are to each other as the squares of the homologous dimensions, it is seen that a narrowing of the same kind of the glottic opening must intercept the passage of air in very different degrees."

And Legallois† sums up his remarks as follows: "The diminution of the glottic opening varies according to the species, and much more even according to the age in certain species. In dogs, and especially in cats, it is so considerable that these animals are suffocated as quickly, or nearly so, as if one had ligatured their trachea. In proportion to the growing up of these animals the danger becomes less pressing, and when they have arrived at a certain age they are only slightly inconvenienced by it (namely, by the diminution of the glottis); this, at least, is so in dogs. From this it follows that of all the symptoms which are produced by section of the par vagum, the gravest ones, those that kill most quickly, are in certain cases those which depend upon the larynx. On the whole, whenever the difficulty of breathing becomes very severe immediately after this operation, it is very likely that its principal cause is in the larynx; for instance, the violence with which the dyspnœa declares itself suddenly in horses, even in adult ones, and the promptitude of their death show that in these animals the glottis is considerably narrowed. A large opening made in the trachea furnishes simultaneously both the remedy for and the etiology of all these cases. *The chink of the glottis, therefore, is never the same in the living subject as is found in the cadaver, and the arytenoid cartilages need being supported by their*

* 'Nouveaux Éléments de Physiologie,' 2 edit., vol. 11, p. 436.

† *Ibid.*, p. 231, *et seq.*

muscles just as the upper eyelid needs the support of its own." (The italics are my own.)

So far Legallois. I have quoted him at length, first, because the results of his experiments have, in the main, been corroborated by practically every observer who has repeated his experiments; and, secondly, because it appeared to me most interesting that the same thesis, the establishment of which is attempted in this paper, should have been given out with almost prophetic foresight at the beginning of the century by practically the first worker in this field.

There is no need to quote at any length the experiences of subsequent experimenters, as they agree on all the main points with Legallois' results, and as the whole literature of the subject has been most carefully quoted and abstracted by Frey in the excellent prize essay already mentioned. The general result of all these experiments may fairly be thus summarised:—that the effects of the sudden reduction of the glottis to its cadaveric width vary very considerably, first, with regard to the species; secondly, with regard to the age of the animal experimented upon; thirdly, though in a less degree, with regard to individual peculiarities of the animal. Whilst certain species, such as cats and horses, not only in the first days after birth but even when adult, are suffocated by the reduction of the glottis to the cadaveric size, other species, notably dogs, suffer less and less in proportion to their ages, so that, whilst they die when operated upon a few days after birth, dyspnœa only occurs on exertion when they are operated upon when adult. Again other species, such as rabbits and guinea-pigs, are not nearly so much inconvenienced as the species so far mentioned, even when operated upon at a very early period of their existence.

Thus the general effect, in animals, of reduction of the glottis to the cadaveric size during life is undoubtedly interference with respiration, but the *degree* of interference immensely varies. Obviously, under these circumstances, it is not permissible to draw hard and fast conclusions from experiments on animals with regard to the degree of interference which may be expected under similar conditions in man, and the only reasonable conclusion which can be drawn is that in all probability reduction of the human glottis to the cadaveric position would also lead to *some* interference with normal respiration, and more so in the young human subject than in the adult.

Even less satisfactory than experiments on animals are pathological observations on man for the decision of the question whether reduction of the glottis to the cadaveric width interferes with normal respiration. It is perfectly true that nearly all observers* who have

* For instance, v. Ziemssen, 'Handbuch der speciellen Pathologie,' vol. 4, pt. 1, p. 456; Morell Mackenzie, *loc. cit.*, p. 440; Gottstein, *loc. cit.*, p. 259, &c.

described cases of bilateral paralysis of the recurrent laryngeal nerves (which are extremely rare) agree that there is no dyspnœa when the patients are at rest; but then two circumstances combine to render the value of this statement rather doubtful for the decision of the point here at issue.

In the first place, it is more than likely that only those *coarser* differences of respiration which are termed "eupnœa" and "dyspnœa" respectively have met with attention on the part of clinical observers, and that, as no actual dyspnœa in the clinical sense of the term was met with in such patients when at rest, *finer* differences in the type of respiration, such as intensification or acceleration of respiratory movements on very slight exertion, were not particularly studied. Moreover, some of these observers, as for instance Solis Cohen,* indeed, speak of "moderate dyspnœa" on exertion occurring sometimes under such circumstances.

Secondly, however, a very important element, not mentioned so far, here comes into consideration, namely, the wonderful adaptability of the human organism to very considerable changes in the respiratory conditions, *provided that these changes are produced slowly.* It is an every-day observation with laryngologists, that an *acute* stenosis of the larynx, such as produced, for instance, by acute œdema, interferes, even if by no means very considerably, yet in a much higher degree, with respiration, and produces much greater subjective and objective dyspnœa, than a much higher degree of stenosis due to *chronic* affections, such as growths in the larynx, bilateral paralysis of the glottis openers, cicatrices after ulcerative disease, congenital membranes expanded between the vocal cords, &c.

Now in almost all cases in which bilateral paralysis of the recurrent laryngeal nerves (*i.e.*, the pathological equivalent during life to the cadaveric position of the glottis after death) is produced, the course of events is a very slow one, and the patients have ample time to adapt their entire respiratory mechanism to the altered conditions of the larynx. Under such circumstances, their whole mode of respiration is instinctively changed to such a degree, that the effects of the reduction of the glottis to the cadaveric size are not likely to attract prominent attention.

Yet there can be no doubt in my opinion that in cases of reduction of the glottis to the cadaveric size, except when the act of respiration is at its lowest physiological ebb, *i.e.*, during *complete* rest of the body, a modification of the mechanism of respiration does occur as soon as any demand is made upon the respiratory apparatus.

This opinion is not purely theoretical.

I have never had the opportunity of observing a case of quite complete bilateral paralysis of the recurrent laryngeal nerves, but I have

* *Loc. cit.*, p. 144.

been able for a long time to follow a case in which quite analogous conditions had been produced by perichondritis of the larynx ending in anchylosis of the crico-arytenoid articulations, the cords being fixed in the cadaveric position. The width of the glottic base, measured with the graduated mirror, completely corresponded with about the *maximum* of that seen after death in that it was between 5 and 6 mm. (the patient was a woman). There were no other laryngeal lesions interfering with the calibre of that organ, nor any other affections causing diminution in the calibre of the air passages. The patient when at *complete* rest breathed quietly and without any effort; the number of her respirations per minute was on the average 20. As soon, however, as she was told to twice pace up and down the length of the room in which she was examined, and then to sit down again, the number of her respirations at first very considerably increased, viz., to 36 or 40, then gradually the frequency diminished, but the inspirations became much more intense, the contraction of the scaleni being distinctly visible, and the levatores alæ nasi perceptibly acting. It always took some time until the previous quiet type of respiration was re-established. The patient complained of *considerable* dyspnœa on however slight exertion.

Thinking that a more positive reply to the question might be obtained by a study of the effects in man of *sudden* diminution of the calibre of the glottis to the cadaveric width, such as are unintentionally produced sometimes by section of the recurrent laryngeal nerves during operations for the removal of goîtres, I addressed in 1884 a collective question to several colleagues* as to the respiratory phenomena after sudden bilateral section, of paralysis of the recurrent laryngeal nerves, and of even unilateral paralysis in children. The latter question was inspired by the wish to learn whether, analogous to the conditions observed in young animals, even a minor degree of diminution in the young human subject might lead to considerable respiratory disturbance, a very interesting case reported by Sommerbrodt† having shown that unilateral paralysis of an abductor muscle of the vocal cord (which in the adult so far as respiration is concerned is perfectly harmless) suffices in a child of 1½ year to produce most grave dyspnœa necessitating tracheotomy.

I regret to say that this question has not been productive of any satisfactory reply.

In a paper published since by Jankowski,‡ some statements occur which are of interest in connexion with the subject of the present investigation, inasmuch as they refer to cases in which both recurrent

* 'Internationales Centralblatt für Laryngologie,' &c., 1884, p. 40.

† 'Breslauer Aerztliche Zeitschrift,' No. 10, 1881.

‡ "Lähmungen der Kehlkopfmuskeln nach Kropfexstirpation" ('Deutsche Zeitschrift f. Chirurgie,' vol 12).

laryngeal nerves appear to have been damaged during the operation. Unfortunately, however, the reports are in part incomplete, and moreover the alterations in the calibre of the trachea due to the previous direct compression by the constricting goître also appear to have in many of them played a considerable part in the production of the respiratory phenomena observed after the operation. Thus these cases are by no means pure, and can hardly be made use of for a decision of the question at issue. The most important of them perhaps is one reported by Riedel,* in which, either due to inundation of the wound with carbolic acid solution, or, as would seem more probable, to tearing of the recurrent laryngeals in the course of the operation, within two hours from its end dyspnœa developed. Still even in this case evidence is not pure, as one of the pneumogastric nerves was simultaneously damaged, and the dyspnœa may have been in part referable to this cause.

Thus pathological observation on the human subject so far offers a much less complete reply to the question concerning the effect of the reduction of the glottis to the cadaveric width than might be theoretically expected, and this point will certainly demand continued attention.

All that can at present be fairly said, is that the evidence points in the direction that reduction of the glottis to the cadaveric size involves, upon the commencement of any effort, however small, some alteration in the type of respiration.

Although the evidence concerning the effects upon the respiration in man of the interpolation of the phonatory apparatus leaves a good deal to be desired, as shown in the last two chapters, there can be no doubt, I think, that its whole tenour goes to show, as would, indeed, be expected from the anatomical facts above demonstrated, that this interposition presents a considerable hindrance to the function of quiet respiration, and that for the fulfilment of the latter function it had to be counterbalanced or neutralised to a certain degree.

This neutralisation could evidently have been effected in one of two forms, namely, either in the form of a rhythmical widening and closure of the glottis, such as commonly is supposed to exist even during tranquil respiration, or in the form of a *tonic dilatation* of the glottis during both phases of quiet respiration (inspiration and expiration), supplying the minimum of space compatible with the ingress and egress of that amount of air to the lower air passages which is required for the purposes of what we call normal quiet respiration.

It has been shown in the preceding chapters that both these alternatives are actually met with in the quiet respiration of men, and it is hardly necessary to say that they do not in the least exclude

* 'Centralblatt für die med. Wiss.,' 1882.

one another. On the contrary, the tonic opening of the glottis may and does at any moment under the influence of emotion, mechanical effort, will, reflex irritation, &c., give way to a rhythmical widening and narrowing of the glottis, and this again on return of normal conditions gives way to the tonic state of widening above described. There can, however, be no doubt that this tonic condition is, much more than rhythmic movements, representative of the participation of the larynx in quiet respiration of *man*. This has been amply demonstrated by the mutual proportions described in a previous paragraph.

The question now arises: What does this tonic widening represent, and how is it produced?

It has already been mentioned that it may represent as well a state of tonic innervation of *both* the glottis openers and glottis closers, with preponderance of the former, or, secondly, a tonic innervation of the abductor muscles alone.

The existence of the first-named condition has been very ingeniously argued for by Rosenbach in the paper referred to above. He writes as follows: "The more complete and delicate the innervating mechanism and the active muscular apparatus are, the more exact must, no doubt, be the co-operation of the muscular groups in question. Now, the action of the vocal cords during respiration and phonation requires an extraordinarily delicate mechanism, and the position of the arytenoid cartilages depends in a high degree on the co-operation of all muscles attached to them. Nay, disturbances would have to be registered far more frequently than is now the case if an extensive vicarious action of healthy muscles were not possible, replacing those disabled from fulfilling their functions. It is, therefore, probable that during the normal position of the vocal cords nervous impulses are constantly carried down to both adductors and abductors, but that the abductors, being the stronger muscles, preponderate, just as in other muscular territories even during quiescence the activity of the extensors preponderates. The stronger the inspiratory innervation is, the more will the glottis become opened, and the expiratory constriction, so trifling during quiet respiration, is very likely to be considered mostly as a remission of the innervation of the abductors, *i.e.*, as a more passive occurrence."

In spite, however, of this clever advocacy of a preponderance of the abductors over the adductors, both being supposed to act simultaneously, the theory seems to me not tenable from whatever point of view it be examined. Anatomical, physiological, and pathological facts equally militate against it.

In the first place, it is not easy to understand how the abductors, being in number and aggregate amount of muscular tissue inferior

to their antagonists, could, anatomically considered, be the stronger ones, as supposed in Rosenbach's hypothesis.

Secondly, the abductors and adductors of the vocal cords, though, in a certain sense, obviously antagonistic to each other (in that they serve the diametrically opposed functions of opening and closing the glottis), yet are not in the same sense antagonists as the extensors and flexors of a limb. In the case of the latter, the different groups of muscles presiding over the movements of the part serve purposes *identical* in nature and in physiological value; in the case of the laryngeal muscles, however, not only are the functions different in physiological importance, but certainly also to some degree quite *independent* of one another. Whilst it is undoubtedly true that no phonatory effect can take place without respiratory movements at the same time coming into play—for phonation is a sort of modified expiration—yet the reverse of this does not hold good, respiration being in no way necessarily connected with phonation. There is, therefore, no reason why, in the performance of a function which is independent of that subserved by the antagonistic group of muscles, the latter ought to come constantly into play.

Rosenbach's comparison, therefore, of the laryngeal muscles with those of the limbs cannot in this respect be admitted to be unreservedly applicable.

Thirdly, if both groups of muscles, the abductors and adductors, were in reality constantly and simultaneously innervated during quiet respiration, and if the abductors merely predominated, one would naturally expect that, in cases of isolated paralysis of the glottis closers, such as in functional aphonia, the glottis should appear much wider in quiet respiration than when seen under ordinary circumstances. For, under such circumstances, the respiratory tonic innervation of the glottis openers would continue to the same degree, whilst the antagonistic innervation of the glottis closers, which, according to Rosenbach's theory, must previously have counterbalanced, to some extent, their abducting force, was absent. Yet the glottis of persons suffering from bilateral paralysis of the glottis closers during quiet respiration is not at all wider open than that of normal persons. This again speaks very forcibly against the hypothesis of a simultaneous innervation of the adductors and abductors with preponderance of the latter.

Fourthly, the fact independently demonstrated by Rosenbach himself in the paper referred to and by me* in several publications, viz.,

* (*a.*) "Clinical remarks on the proclivity of the abductor fibres of the recurrent laryngeal nerve to become affected sooner than the adductor fibres, or even exclusively, in cases of undoubted central or peripheral injury or disease of the roots or trunks of the pneumogastric, spinal accessory, or recurrent nerves" ('Archives of Laryngology,' vol. 2, 1881, p. 203).

that the abductors of the vocal cords are more easily disabled by any organic mischief acting upon their nerve supply than the adductors, and that they die sooner after the death of the individual than the adductors,* can hardly be reconciled with the idea of a preponderance of their physiological strength over that of the adductors.

Fifthly, the central conditions of the innervation of the two laryngeal groups of muscles also tell, as I hope to show in a paper which I shall shortly bring before the Royal Society in conjunction with Professor Victor Horsley, against the physiological preponderance of the abductors over the adductors.

Sixthly and lastly, the *coup de grâce* is given to this idea by the fact that stimulation of the cut end of the recurrent laryngeal in most species of animals (except the cat) results—if no undue influence of the anæsthetic used during the experiment comes into play†—in the corresponding vocal cord being drawn towards the middle line, *i.e.*, the adductors preponderate over the abductors, though both groups of fibres are equally strongly stimulated. This fact, needless to say, is wholly incompatible with the idea of preponderance of the abductor over the adductor muscles.

Thus from whatever point of view the question of the simultaneous innervation of the adductors and abductors, with preponderance of the latter during quiet respiration, be looked upon, there is no evidence for the existence of such a condition, and there are many arguments against it.

It is, indeed, much more probable that there is primarily a strict differentiation between the two antagonistic groups of laryngeal muscles (the phonatory and respiratory ones) and that, though there is under certain circumstances a *transition* of the functions of the one into those of the other, yet for the purposes of respiration under ordinary circumstances the respiratory muscles, *i.e.*, the posterior crico-arytenoid muscles, *alone* are engaged, being during inspiration and during expiration in a state of *semi-tonus*, in order to counterbalance the partial obstruction created by the interpolation of the phonatory into the respiratory apparatus.

This idea, indeed, more or less clearly expressed, has been before the minds of a good many of those who since the beginning of this century have worked in this field of investigation. It has been shown above that Legallois was quite conscious of the necessity of such a tonus existing. Luschka, again (*loc. cit.*), and Schech (*loc. cit.*)

(*b.*) "Ueber die Lähmung der einzelnen Fasergattungen des Nervus laryngeus inferior (recurrens)" ('Berl. Klin. Wochenschrift,' 1883, No. 46, *et seq.*).

* "On an apparently peripheral and differential Action of Ether upon the Laryngeal Muscles." By Felix Semon and Victor Horsley ('British Medical Journal,' 4 and 11 Sept., 1886).

† Compare the last-named paper by Semon and Horsley, p. 31.

speak very clearly of the necessity of the existence of a similar arrangement. The full physiological importance of it, however, appears to have only comparatively recently occurred to Krause and to myself, independently of one another, and to have been brought forward equally independently and simultaneously at the International Congress of 1884, as stated at the beginning of this paper.

The existence of such a tonus fully explains the difference between the conditions of the glottis as seen during quiet respiration and after death, and explains also why the interposition of the phonatory apparatus in the air passages has not been followed by any change in the type of normal respiration in man. In virtue of their preventing such a change, *i.e.*, of either increased labour on the part of the regular muscles of respiration or of the accessory muscles of respiration having to work constantly even during quiet respiration, the glottis openers, *i.e.*, the posterior crico-arytenoid muscles, appear to me *to deserve undoubtedly a much higher position in the mechanism of respiration than has been so far accorded to them.*

The only remaining question then would be: is this tonus of the abductor muscles an *automatic* one? *i.e.*, is it induced in the respiratory centre *itself*, or is it of the nature of a *reflex* tonus, *i.e.*, only engendered in the respiratory centre through *peripheral* influences?

Athough it has been shown by Rosenthal that the respiratory centre in the medulla oblongata, even after the section of both pneumogastric nerves, and after removal of the cerebrum as well as after section of the cervical part of the spinal cord, is capable of engendering rhythmic movements (so that its action in a certain sense must certainly be looked upon as an automatic one), yet at the same time there can be no doubt as to the existence of afferent impulses communicated to it along the most various peripheral nerves, and most of all along the main trunk of the pneumogastric. Whilst therefore, *a priori*, it would not at all be impossible that the tonus of the abductors of the vocal cords might *originate* in the respiratory centre itself, it seemed, in concord with general experiences concerning the nervous mechanism of respiration, at least equally probable, that impulses might be conducted *rhythmically* along the afferent fibres of the pneumogastric nerves to the respiratory centre, and there be changed into a *tonic* semi-innervation of the posterior crico-arytenoid muscles, which again under the influence of any of the extraneous causes above mentioned could be changed into rhythmical impulses coincident with and renewed with every respiratory movement.

It occurred to me that a more definite solution of this question might be hoped for, if it were possible to cut both pneumogastric nerves *below* the points from which the recurrent laryngeal nerves are given off. One could not hope that this experiment would defi-

nitely settle the question, because in animals, especially under the influence of anæsthetics, only rarely is a condition observed during respiration analogous to that seen in quiet respiration in man, their vocal cords, on the contrary, making very energetic rhythmical excursions. Still, it seemed legitimate to submit this question to experimental proof, because, even with these respiratory excursions, it was to be expected that if respiratory influences governing the action of the glottis-openers reached the respiratory centres along the trunks of the *pneumogastric* nerves, the excursions of the vocal cords after section of the latter would very much *diminish in intensity*, and, if they were *exclusively* conducted along these paths, that after section of the pneumogastrics below the points of departure of the recurrents, the glottis would not open any further than to the *cadaveric* position.

Professor Victor Horsley was kind enough to submit these theoretical considerations to experimental proof. On April 17, 1890, he, in the presence of Mr. Embleton and of myself, performed the following experiment: A small adult female fox terrier was etherised and tracheotomised; the narcosis was afterwards kept up with chloroform. First the right, afterwards the left, vagus was laid bare, and both nerves were cut about 1 centimetre below the points where the right recurrent laryngeal winds round the subclavian artery and the left round the aorta. As soon as the pleura was opened in order to get at the left vagus, artificial respiration was started and maintained until the end of the experiment.

Whilst previous to the cutting of the right vagus (and also after the division) the thorax as well as the vocal cords made *very extensive* and energetic rhythmical respiratory excursions (the glottis during inspiration being opened to its fullest extent), the respiratory excursions of the cords were, after section of the second vagus (the left), equally energetic but much less extensive, the glottis during respiration opening only to the cadaveric position.

The animal was killed by asphyxia; during its final forcible respiratory efforts the glottis again opened, during inspiration, to its *fullest* extent.

Dissection after death showed that both recurrent nerves were quite uninjured.

This experiment certainly went far to prove that respiratory impulses influencing the action of the posterior crico-arytenoid muscles reached the respiratory centre, and, more precisely speaking, the ganglionic centres of these abductor muscles, through the medium of the pneumogastric nerves. At the same time the full dilatation of the glottis during the asphytic stage of the animal, seemed to point out that the impulses thus engendered cannot be the only ones reaching these ganglionic centres, and that the respiratory centre, so far as the

larynx is concerned, may also be influenced through other afferent impulses.

To settle this point, if possible, more definitely, the experiment was repeated on May 8, 1890. A small castrated fox terrier was etherised and tracheotomised. Narcosis was afterwards kept up by ether. The right vagus was laid bare below the line of departure of the right recurrent laryngeal nerve. Both cords made very energetic and extensive rhythmical respiratory excursions. The right vagus was cut more than 1 cm. below the point of departure of the right recurrent laryngeal nerve. Both cords continued their excursions as if nothing had happened.

A subcutaneous injection of 5 grains of acetate of morphia was now made into the dog's thigh, the left vagus was then exposed, artificial respiration being started as soon as the pleura was opened previous to the section of the left vagus. It was again ascertained that the glottis still opened at *maximum* during inspiration. The left vagus was then cut about 1 cm. below the arch of the aorta, and it was now observed that, together with very considerable slowing of the two phases of respiration, the glottis, though it still opened widely, and certainly much beyond the cadaveric position, yet no longer opened *nearly* as widely as before, when the vocal cords during inspiration actually completely disappeared from view.

A very remarkable phenomenon was observed in connexion with the artificial respiration. Whenever the dog's lungs were *well* aerated, the excursions of the cords, though good, corresponded to the description given above of the conditions as occurring after section of the vagi, but as soon as asphyxia became threatening the glottis at once opened, as previously to the section, *ad maximum*.

The dog was killed by asphyxia. *Post-mortem* examination showed that both vagi had been cut very considerably below the points where the recurrents were given off, and that the latter were quite uninjured.

This experiment, then, in every respect tends to corroborate the conclusions drawn from the former, *i.e.*, that whilst the inspiratory impulses which act upon the ganglionic centres of the abductor muscles and which in animals more frequently induce rhythmical excursions of the vocal cords, but in man tonic semi-dilatation of the glottis, are of a *reflex* character, and are mainly conducted along the pneumogastric nerves, yet the latter are by no means the only source of this reflex innervation.

The question raised in the foregoing paragraphs will certainly demand still further elucidation, and the results arrived at in this paper will no doubt have to be checked by future observers. Still I think that, as the outcome of the investigation, so far as it has been conducted, the following conclusions may be drawn :—

First, the glottis in man is wider open during quiet respiration (inspiration and expiration) than after death or after division of the vagi or recurrent laryngeal nerves.

Second, this wider opening during life is the result of a permanent activity (tonus) of the abductors of the vocal cords (posterior crico-arytenoid muscles) which, therefore, belong not merely to the class of accessory, but of regular, respiratory muscles.

Thirdly, the activity of these muscles is due to tonic impulses which their ganglionic centres receive from the neighbouring respiratory centre in the medulla oblongata. It is very probable that these impulses rhythmically proceed to the respiratory centre from the stimulation of certain afferent fibres contained mainly, but not exclusively, in the trunks of the pneumogastric nerves, and that they are in the respiratory centre changed into tonic impulses. The regular activity of the abductors of the vocal cords during life, therefore, belongs to the class of reflex processes. The permanent half-contraction of these muscles, in which form their tonic innervation is manifested, can be further increased, in concord with the general laws of the mechanism of respiration, by either volition or other reflex influences.

Fourthly, in spite of their extra innervation, the abductors of the vocal cords are physiologically weaker than their antagonists.

Fifthly, these antagonists, the adductors of the vocal cords, have primarily nothing at all to do with respiration and ordinarily serve the function of phonation only. Their respiratory functions are limited to

(*a.*) Assistance in the protection of the lower air passages against the entry of foreign bodies;

(*b.*) Assistance in the modified and casual forms of expiration known as cough and laughing.